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__Atmospheric dispersion and Consequences of a UF₆ Release
Caused by valve Rupture on a Hot 30B Cylinder__

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ATMOSPHERIC DISPERSION AND CONSEQUENCES OF A UF$_6$ RELEASE CAUSED BY VALVE RUPTURE ON A HOT 30B CYLINDER

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The accident analysed is that of valve rupture on a 30B cylinder heated to 100°C and containing UF$_6$, thus causing gaseous UF$_6$ to escape.

Most of the UF$_6$ content of the cylinder is initially in liquid form. This liquid phase will start to boil and the gas will flow out. The contents of the cylinder will then be cooled due to the dissipation of the latent heat of evaporation.

1. Calculation of the discharge rate and proportion discharged.

The calculations are based on the following simplifications:

1) The behaviour of the cylinder contents is considered to be adiabatic, i.e. no cooling is considered to take place through the walls.

2) The material transport resistance during boiling is ignored.

3) The pressure-volume work in the gaseous phase can be considered as negligible as compared to the heat dissipation in the form of latent heat of evaporation.

From the risk aspect, all of these assumptions are pessimistic. If free convection in air is assumed to occur on the outside of the cylinder, assumption 1) will give an accessively low cooling rate.

Assumption 2) gives a somewhat high discharge rate, since the pressure in the cylinder at any instant will be equal to the equilibrium pressure at the prevailing temperature. However, the deviation should be very small. But it is difficult to specify how small this deviation is, since an analysis of the material transport resistance during boiling is complicated and is outside the scope of this study.

Assumption 3) gives a cooling rate which is about 0.1 - 0.2% too low.

When the temperature in the cylinder has fallen to the triple point, crystallisation will start. This is assumed to take place at a constant temperature, i.e. the crystallisation rate is assumed to be determined by the dissipation of the latent heat of evaporation.

When crystallisation has been completed, it is assumed that discharge will cease. The triple point is assumed to be about $64^{\circ}C$ and the temperature at which the steam pressure above solid UF_6 is 1 atm is approx. $54^{\circ}C$. The specific heat capacity of solid UF_6 within this temperature range is approx. 120 cal/kg, K. The heat of sublimation is 33 000 cal/kg, K. The quantity of UF_6 which would flow out of the cylinder after completed crystallisation (if the cylinder is assumed to contain 500 kg of solid phase) would thus be

$$\frac{120(64-54)}{33\ 000} \cdot 500 \simeq 20 \text{ kg}$$

1.1 Discharge relationships.

The following is based on the Chemical Engineers' Handbook, Perry et al. (5).

The maximum mass velocity on isothermal expansion can be calculated from:

$$G_{ci} = P_o \sqrt{\frac{M}{2.718 \cdot R \cdot T_o}} \quad (kg/m^2 \cdot s) \qquad (1)$$

where P_o = pressure in the container (Pa)

M = molecular weight of UF_6 = 355 (kg/kmol)

T_o = temperature in the container (K)

R_o = universal gas constant = 8314 (J/kmol, K)

G_{ci} is multiplied by a factor F which is a function of the ratio of the pressure in the container and the ambient pressure ε, the discharge resistance N and the isentropic index k. The value of F is specified graphically in the Chemical Engineers' Handbook.

The discharge resistance consists of two components, i.e. sudden restriction with N $\simeq$ 0.5 and discharge into a large recipient with N $\simeq$ 1.0.

UF_6 has a very low isentropic index k = 1.06, i.e. it behaves almost isothermally on expansion. With these values of N and k, the graph in the Chemical Engineers' Handbook is described reasonably well by the following equations:

$$F = 0.76 \qquad\qquad \varepsilon < 0.45 \qquad (2a)$$

$$F = -1.18381 \cdot \sqrt{\varepsilon} -1.463735(\varepsilon -0.75)^2 +1.68141 \qquad (2b)$$
$$0.45 \leq \varepsilon \leq 0.75$$

$$F = 1.18381 \cdot \sqrt{\varepsilon} -4.464022(\varepsilon -0.75)^2 +1.689192 \qquad (2c)$$
$$0.75 < \varepsilon < 0.95$$

$$F = -7 \cdot \varepsilon + 7 \qquad\qquad \varepsilon \geq 0.95 \qquad (2d)$$

The relative error in relation to the graph is below 2%, which is well within the reading accuracy in the graph.

The total flow out of the cylinder will be:

$$G = G_{ci} \cdot F \cdot A_{hole} \qquad (3)$$

where A_{hole} = cross-sectional area (m^2) of the discharge hole.

From equations (1) and (3), and at a 1 inch diameter discharge hole, the discharge flow will be:

$$G = 6.43 \cdot F \cdot P_1 \cdot T_o^{-1/2} \qquad (4)$$

where P_1 = pressure in the cylinder (atm).

If the discharge hole is instead assumed to have the same diameter as the major diameter of the valve thread, i.e. 1 11/32 in, the discharge flow will instead be:

$$G = 11.62 \cdot F \cdot P_1 \cdot T_o^{-1/2} \qquad (5)$$

This clearly illustrates the uncertainty of the discharge calculation.

1.2 Material - energy balances.

A material balance on the container gives:

$$\frac{dm}{dt} = -G \qquad (6)$$

where m = mass of UF_6 in the cylinder (kg).

If the pressure volume work is ignored and the standard condition is set for the liquid at the prevailing temperature, an energy balance gives:

$$m \cdot C_p^{tot} \cdot \frac{dT}{dt} = -G \cdot \Delta H_{vap} \qquad (7)$$

where ΔH_{vap} = latent heat of evaporation (J/kg)

C_p^{tot} = the weighted mean value of the specific heat capacities of the gaseous and liquid phases (J/kg, K).

$$C_p^{tot} = \frac{m_g \cdot C_p^g + m_L \cdot C_p^L}{m} \qquad (8)$$

where m_g = mass of the gaseous phase in the cylinder (kg)
m_L = mass of the liquid phase in the cylinder (kg)

From (7) and (8):

$$\frac{dT}{dt} = -G \cdot \Delta H_{vap} / (m_g^- \cdot C_p^g + m_L \cdot C_p^L) \qquad (9)$$

The masses of the gaseous and liquid phases can be obtained by knowledge of the total volume of the cylinder, the total mass of UF_6 in the cylinder and the density of the liquid phase. From the universal gas law:

$$m_g = \frac{M \cdot P_1 \cdot V_g}{R \cdot T_o} \qquad (kg) \qquad (10)$$

where V_g = volume of the gas in the cylinder.

But $V_g = V_{tot} - V_L = V_{tot} - m_L/\rho_L$, which gives:

$$m_L = (m - \frac{M.P_1}{RT_o} \cdot V_{tot})/(1- \frac{M.P_1}{R.T_o} \cdot \frac{1}{\rho_L}) \qquad (11a)$$

$$m_g = m - m_L \qquad (11b)$$

Differential equations (6) and (9) are solved simultaneously by the Runge-Kuttas method.

To solve equations (11a) and (9), expressions are necessary for c_p^g, c_p^L, H_{vap}, ρ_L and P_1 as a function of the temperature. These expressions have been taken from (3):

$$c_p^g = 382.8 + 0.09366 \cdot T - 3.785 \cdot 10^6/T^2 \qquad (12)$$

$$c_p^L = 211.907 + 0.76751 \cdot T + 7.87236 \cdot 10^6/T^2 \qquad (13)$$

$$\Delta H_{vap} = 29193.09 + 170.86 \cdot T - 0.33692 \cdot T^2 +$$
$$+ 1.1657 \cdot 10^7/T \qquad (14)$$

$$\rho_L = 4041 + 3.368 \cdot T - 0.0136 \cdot T^2 \qquad (15)$$

$$P_1 = \exp (7.2876 \cdot \ln T - 0.014371 \cdot T - 1245.2 \cdot T^{-1} -$$
$$- 248608 \cdot T^{-2} - 31.2935) \qquad (16)$$

The mass of the crystal phase is obtained from

$$\frac{dm_s}{dt} = G \cdot \Delta H_{vap}/\Delta H_{fus}$$

where ΔH_{fus} = latent heat of fusion (kJ/kg)

m_s = mass of the crystal phase.

2. Results of the discharge calculations.

A computer program known as "HEXRISK" has been written for the discharge calculation. This program which calculates the mass of UF_6 in the cylinder, the temperature, pressure, flow and the proportion discharged as a function of time following valve rupture, has been run a total of four times, assuming three different starting temperatures and two diameters of the discharge hole:

Run No. 1: $T_o = 100^{\circ}C$, d = 1 11/32"

Run No. 2: $T_o = 90^{\circ}C$, d = 1"

Run No. 3: $T_o = 100^{\circ}C$, d = 1"

Run No. 4: $T_o = 110^{\circ}C$, d = 1"

The temperature drop as a function of time in run No.3 is plotted in Fig. 2. The proportion discharged from the cylinder varies between 49% (run No.2) and 56% (run No.4). This corresponds to a total UF_6 discharge of between 1 120 kg nad 1 270 kg. About 20 kg must be added to these figures as the quantity which may be discharged after the uranium hexafluoride has crystallised. These 20 kg can be entirely ignored from the risk aspect, since they represent a very small addition to the exposure in the surroundings and since it is discharged at low velocity. The proportion discharged as a function of time in run No.3 is plotted in Fig.3.

A comparison between runs No.1 and 3 (same temperature but different hole diameter) shows that discharge through the larger hole takes place in about 39 min and through the smaller hole in about 45 min. In both runs, the proportion discharged is 53% (1 200 kg of UF_6 is discharged).

Since the expansion of the cylinder contents was considered to be adiabatic, the proportion discharged is clearly defined by the initial temperature. The influence of reasonable variations in the initial temperature is illustrated by the table below, which applies to a hole diameter of 1 in (runs 2 - 4).

Initial temp.($^{\circ}C$)	Initial press.(atm)	UF_6 discharged (kg)	Proportion discharged (%)	Discharge time (min)
90	3.13	1117	49.1	45.1
100	4.00	1195	52.5	44.8
110	5.03	1271	55.8	44.1

194°F (90), *230°F* (110)

The mean discharge rate $\bar{G}$ and the maximum discharge rate G_{max} will be:

Initial temp.($^{\circ}C$)	$\bar{G}$	G_{max}	$G_{max}/\bar{G}$
90	0.41	0.80	1.95
100	0.44	1.01	2.30
110	0.48	1.25	2.60

The interesting feature from the risk aspect is the ratio of the maximum to the mean discharge rate, i.e. $G_{max}/\bar{G}$. This

ratio provides a rough indication of the concentration in the front part of the plume and the mean concentration. The time for the discharge rate to fall from its maximum value to its mean value is about 9 min at an initial temperature of 90°C, 10.5 min at 100°C and 11.5 min at 110°C. In all runs, the uranium hexafluoride started to crystallise within 15 minutes (the flat part in Fig.2 and 4). The discharge rate during the crystallisation period is constant at 0.37 kg/s at a diameter of 1 in and 0.68 kg/s if the hole diameter is assumed to be 1 11/32 in. The discharge rate in the case of the 1 in hole is shown in graph 4. The fraction of the cylinder content which is discharged before crystallisation starts varies between 16% at an initial temperature of 90°C and 27% at 110°C.

The discharge calculation is somewhat conservative, since the process in the cylinder has been assumed to be adiabatic. The reduction in the proportion discharged caused by heat dissipation to the surroundings through the cylinder walls is of the order of 4% (slightly below 100 kg less UF_6 discharged) under the following conditions:

- The heat transmission resistance in the cylinder wall and inside the cylinder is ignored.

- Cooling takes place by free convection in air on the outside ($\alpha \simeq 10$ W/m²,°C).

- The ambient temperature is 20°C.

3. Sequence_of_events_after_discharge.

Uranium hexafluoride reacts very quickly with water as follows:

$$UF_{6(g)} + 2\ H_2O_{(g)} \longrightarrow UO_2F_{2(s)} + 4\ HF_{(g)}$$
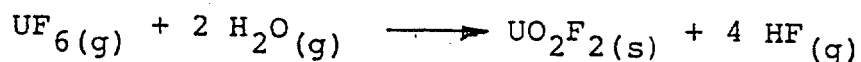
Owing to the high reaction rate, the limiting factor in the reaction of UF_6 with the humidity in the air is considered to be the availability of water in the form of airborne humidity. A mathematical treatment of the transformation of UF_6 in the gas plume formed inevitably leads to extensive calculation work which is outside the scope of this study. A mathematical treatment of this nature must include the diffusion of water vapour in air, the diffusion of uranium hexafluoride in air and the influence of turbulence and temperature gradients. We shall instead discuss the water quantities necessary for complete transformation of UF_6 to UO_2F_2.

In the initial stage, the discharge rate is relatively high. Assuming that the hole is 1 in in diameter, the initial flow is approx. 1 kg/s. This corresponds stoichiometrically to a water demand of 0.1 kg/s for complete transformation. The mean water consumption during the discharge time is approx. 0.05 kg/s for complete transformation.

The water content of the air is dependent on the temperature and the weather conditions (relatively humidity) and can easily be calculated by means of the vapour pressure table (see table below). On the basis of the water content in the air, an assessment can then be made of the air volume necessary for complete reaction of the UF_6 to take place.

Water content in air (kg/m^3).

RH %	Temp. °C	0	10	20	30
20		$9.7 \cdot 10^{-4}$	$1.9 \cdot 10^{-3}$	$3.5 \cdot 10^{-3}$	$6.1 \cdot 10^{-3}$
60		$2.9 \cdot 10^{-3}$	$5.6 \cdot 10^{-3}$	$1.0 \cdot 10^{-2}$	$1.8 \cdot 10^{-2}$
100		$4.8 \cdot 10^{-3}$	$9.2 \cdot 10^{-3}$	$1.7 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$

Air volume (m^3/s) necessary for complete reaction at the mean discharge rate.

RH %	Temp. °C	0	10	20	30
20		52	26	14	8.2
60		17	8.9	5.0	2.8
100		10	5.4	2.9	1.7

Total air volume (m^3) necessary for complete reaction.

RH %	Temp. °C	0	10	20	30
20		140 000	70 000	38 000	22 000
60		46 000	24 000	14 000	6 700
100		27 000	15 000	7 800	4 600

Under extremely humid summer conditions, the air volume necessary corresponds to a sphere with a radius of 10 m (or a cone with an apex angle of 10° and a length of 83 m) to convert all of the uranium hexafluoride to uranyl fluoride. If dry winter weather is instead assumed, the corresponding sphere of air would have a radius of 31 m and the cone would have a length of 260 m.

In humid weather at the height of summer, it would therefore appear probable that most of the uranium hexafluoride would be converted to UO_2F_2 in the immediate vicinity of the discharge point (within 100 m), whereas during the winter or in dry weather, part of the UF_6 will probably be spread outside the plant boundary.

Two additional questions, which have not yet been discussed, also have an effect on the spreading of uranium in the surroundings. One of these concerns the cooling of UF_6, and the consequent formation of aerosols and crystallisation. The other question is the particle size of the UO_2F_2 crystals, i.e. how quickly these can be expected to settle on the ground. The fact that the reaction between UF_6 and the moisture in the air is very fast suggests that the particle size could be very small and that the crystals could then be transported across long distances by the wind. Since the basis for determining the spreading of uranium is uncertain, it is assumed in the consequence calculations that most of it is entrained by the wind, primarily in the form of UO_2F_2 particles.

4. Reaction in air.

Uranium hexafluoride reacts with the water in the air and forms uranyl fluoride and hydrogen fluoride as follows:

$$UF_6 + 2 H_2O \longrightarrow UO_2F_2 + 4 HF$$

The reaction takes place instantaneously. The limiting factor is the amount of water vapour in the air. As mentioned earlier, this study does not include complete treatment of the actual reaction of UF_6, and the calculation is based on the assumption that complete transformation of UF_6 takes place.

As mentioned earlier, the reaction leads to the formation of hydrofluoric acid (HF) and uranyl fluoride (UO_2F_2). The radiological toxicity consists only of uranium which occurs here in soluble form as uranyl ions (UO_2^{2+}). The chemical toxicity is due to the hydrogen fluoride, the fluoride ions and the uranyl ions.

Radiological toxicity.

Under certain conditions, uranium accumulates in the skeleton, where it has a biological half-life of 300 days. The radiological toxicity increases with increased enrichment of the uranium. The highest permissible concentration in air for persons engaged on non-radiological work is $3 \cdot 10^{-12}$ μ Ci/cm^3. The maximum permissible single intake of uranium by breathing is 2.5 mg/day and by swallowing, 150 mg/day. At low enrichment, the critical organs are the kidneys.

Chemical toxicity.

Hydrofluoric acid at room temperature is a colourless liquid with a pungent smell. The acid is entirely soluble in water. In gaseous as well as liquid form, the acid attacks the eyes, skin and mucous membranes. The acid is classified as a digestive poison, a respiratory poison and a nervous poison.

The hygienic limit for hydrogen fluoride in air is 3 ppm. The inhalation of vapour or gas corresponding to 50 ppm for 30 - 60 minutes is lethal.

Hydrofluoric acid reacts very readily with oxidising as well as reducing agents, and hydrogen is liberated in the reaction. The acid also reacts violently with metals and hydrogen is liberated. The hydrogen is very flammable and may form explosive mixtures with air.

Since it is soluble, uranyl fluoride owes its toxicity to that of the uranyl ion and that of the fluoride ion.

When breathed in, soluble uranium (UF_6 and UO_2F_2) is quickly transported to the body by the blood. A large proportion is decomposed in the urine. But significant quantities will be retained by the kidneys and skeleton.

If soluble uranium is swallowed, only a small proportion will remain in the digestive tracts. Of this quantity, about 1% will be transported further in the blood.

The primary risk in the inhalation of compounds containing natural and low-enriched uranium is the chemical injury caused to the kidneys rather than the radiological toxicity. A poisoning symptom is the presence of albumen in the urine. On chronic inhalation, the chemical toxicity of uranium is comparable with that of lead. The lethal dose for animals varies between 0.1 mg U/kg of body weight and 20 mg U/kg of body weight. In the case of human beings, this value can be extrapolated to around 1 mg U/kg of body weight.

The toxicity of fluoride is due to it occupying the spaces of hydroxide ions in the apatite lattice of the skeleton. This leads to bone embrittlement.

5. Calculation of the plume.

5.1 Concentration and dispersion

The concentration at ground level along the centre line of the plume can be calculated from:

$$\kappa_0 = \frac{M}{2\pi\sigma_y\sigma_z \cdot u \cdot t} \exp\left(-\frac{h^2}{2\sigma_z^2}\right) \qquad (kg/m^3)$$

where M = quantity discharged (kg)

h = height of discharge (m)

t = duration of discharge (s)

σ_y and σ_z = horizontal and vertical dispersion parameters respectively (m)

u = wind velocity (m/s)

Since no weather statistics are available for Västerås, the weather situation is compared with that applicable to Ågesta. These statistics are considered to be the best available in the country (6) for this type of calculation.

The value of κ_0 for Ågesta is specified in (1) as a function of the weather stability parameter λ and the distance X from the point of discharge. Converted to a discharge of about 1 200 kg of UF_6, the values specified in Table I will be obtained. These values specify the integral concentration given in kg/m^3 for various distances from the point of discharge.

The conversion to concentration in kg/m^3 is shown in Table II. This has been calculated on the basis of the mean discharge flow of 0.44 kg UF_6/s from the cylinder, which has been obtained from the discharge calculations in the preceding chapter.

The weather stability parameter λ corresponds to various weather situations and wind velocities in accordance with the table below:

Weather type	λ	u (m/s)	frequency, %
Neutral	–	5	44
Almost neutral	0.5	5	19
Fairly stable	1.1	4	17
Relatively stable	1.7	3	12
Stable	2.3	2	5
Very stable	2.9	1	3

Fig. 5 - 8 have been produced from these values and the tables in Appendices 2 and 3. Fig. 5 - 6 indicate the integral concentration as a function of the cumulative frequency, and Fig. 7 - 8 show the discharge concentration as a function of the cumulative frequency. All graphs include the distance from the discharge point as a parameter.

The integral concentration and the discharge concentration under average weather conditions (50% cumulative frequency) and unfavourable weather conditions (95% cumulative frequency) have then been read from Fig. 5 - 8 for the various distances from the discharge point. These concentrations are tabulated in Appendices 4 and 5. However, it should be pointed out that the values in the immediate vicinity are very uncertain.

As regards dilution of the plume in the direction of discharge, Tables III - IV show that the concentrations fall off by a factor of 38 between 0.25 and 10 km from the point of discharge under average weather conditions (50% cumulative frequency), whereas they fall off by a factor of no more than 8 under unfavourable weather conditions (95% cumulative frequency).

In the immediately adjacent zone, the difference between the concentrations under average and unfavourable weather conditions is negligible. However, the differences increase with the distance from the discharge point, and at a distance of 10 km, the concentration is a factor of 10 higher under unfavourable weather conditions than in average weather.

Relatively large amounts of data must be processed for accurate calculation of the dilution of the plume perpendicularly to the direction of discharge, i.e. the horizontal width of the plume, at various distances from the point of discharge, but this is considered to lie outside the scope of this study.

However, the width of the plume has been approximately calculated using the graphs in (1). The curves for 50% and 95% cumulative frequencies have been plotted in graph 25 in the above reference. The 50% case was found to correspond well to the curve for neutral weather ($\lambda = -\infty$) and the 95% case corresponds up to 0.5 km from the discharge point to fairly stable weather ($\lambda = 1.1$) and beyond 0.5 km, to relatively stable weather ($\lambda = 1.7$). The plume widths at the various cumulative frequencies and distances were then read from graph 17 and graph 34 in reference (1). These values are tabulated in Table IV. The plume widths indicate twice the distance from the centre line to the point at which the concentration has fallen off to 1% of the concentration at the centre line of the plume.

5.2 Consequences to the general public.

People who are within the plume will be exposed to uranium as well as fluorine in soluble form which they will absorb primarily by breathing.

The duration of the discharge in this particular case is 45 minutes. The respiratory rate has been assumed to be 1.25 m^3/h.

The calculations have been concerned with people who are in the dispersion zone of the plume throughout the discharge time.

Uranium quantities inhaled.

Most of the uranium is inhaled in the form of UO_2F_2. After reaction with water, 1 kg of UF_6 corresponds to approx. 0.9 kg of UO_2F_2 which, in turn, corresponds to approx. 0.7 kg of U.

The uranium is in soluble form throughout. The critical organs are then initially the kidneys and only when the doses are large will the uranium reach the skeleton.

A fraction of 0.25 of the material inhaled is deposited in the lungs and is absorbed by the blood. The amounts of uranium which are absorbed by the human body at various distances from the discharge point are shown in Table VI. This table illustrates that the amount of uranium inhaled is 1 - 2 powers of ten below the lethal dose (approx. 1 mg/kg of body weight) at 50% as well as 95% cumulative frequency. In the immediately adjacent zone, the values are presumably somewhat too low. It is very difficult to calculate the concentration accurately within this zone, since the actual discharge height due to the plume lift is difficult to determine. However, there is no doubt whatever that it is obviously unhealthy to be within this adjacent zone. On the other hand, further away from the discharge point, the amount inhaled is below the permissible limit of 2.5 mg for individual inhalation of soluble uranium.

It would be desirable to carry out a determination of the relationships prevailing in the immediately adjacent zone, to calculate the actual plume lift, etc., in order to obtain more reliable values of the uranium and fluorine contents in this zone.

Quantities of fluorine inhaled.

All fluorine is treated as hydrofluoric acid, since two-thirds are inhaled in this form and since the remaining one-third will form hydrofluoric acid in the body.

When it has reacted with water, 1 ml of UF_6 corresponds stoichiometrically to 6 mol of fluorine. Thus, 1 kg of UF_6 corresponds to 0.33 kg of hydrofluoric acid. The contents of hydrofluoric acid at various distances from the point of discharge have been calculated on the basis of the hypothetical UF_6 concentration (as if no UF_6 had reacted) in Table V. These values are given in Table VII.

The hygienic limit value for hydrofluoric acid is at 2.5 mg/m^3. As shown by the table, the contents on discharge are well below this value outside the immediately adjacent zone. The calculations are also considered to be reliable in this case. As mentioned earlier, the basis for the calculations for the immediately adjacent zone is fairly weak, and the contents may be appreciably higher here than is indicated by the table. Great care should therefore be taken in the immediate vicinity of the

discharge point and a gas mask should be used in the decontamination work.

6.   Proposals for the decontamination work.

As soon as discharge is detected, people should be evacuated from the immediately adjacent zone to a safe area.

The decontamination personnel should work in full-body protective suits and gas masks.

It is presumably impossible to collect the gas in a free gas cloud. Hydrogen fluoride as well as uranyl fluoride are readily soluble in water, and spreading of the cloud can possibly be reduced by spraying it with scattered jets of water. The substances will then be deposited on the ground surface. Water jets can also be used for affecting the direction of travel of the cloud, if this is considered desirable.

The hydrogen fluoride and uranyl fluoride deposited on the ground surface can be neutralised by means of slaked lime. People who are suspected of having inhaled hydrogen fluoride or uranyl fluoride should quickly be taken to a hospital. In the case of hydrogen fluoride poisoning, the patient should be provided with fresh air or, if possible, oxygen, should rest and should be kept warm. The symptoms of hydrofluoric acid poisoning are heavy coughing, shortage of breath and a pronounced general effect.

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Table I

Time-integral of concentration as a function of the weather stability parameter at different distances from the source.

X (km) \ λ	- ∞	0,5	1,1	1,7	2,3	2,9
0,1	$1,8 \cdot 10^{-2}$	$1,6 \cdot 10^{-2}$	$1,1 \cdot 10^{-2}$	$4,0 \cdot 10^{-4}$	-	-
0,25	$3,6 \cdot 10^{-2}$	$3,9 \cdot 10^{-2}$	$4,8 \cdot 10^{-2}$	$3,1 \cdot 10^{-2}$	-	-
0,5	$2,2 \cdot 10^{-2}$	$2,5 \cdot 10^{-2}$	$3,5 \cdot 10^{-2}$	$4,7 \cdot 10^{-2}$	$3,0 \cdot 10^{-3}$	-
1,0	$1,1 \cdot 10^{-2}$	$1,3 \cdot 10^{-2}$	$1,9 \cdot 10^{-2}$	$3,3 \cdot 10^{-2}$	$2,1 \cdot 10^{-2}$	-
2,0	$5,0 \cdot 10^{-3}$	$5,9 \cdot 10^{-3}$	$9,0 \cdot 10^{-3}$	$1,8 \cdot 10^{-2}$	$3,1 \cdot 10^{-2}$	-
3,0	$3,2 \cdot 10^{-3}$	$3,7 \cdot 10^{-3}$	$5,9 \cdot 10^{-3}$	$1,3 \cdot 10^{-2}$	$2,9 \cdot 10^{-2}$	$1,8 \cdot 10^{-4}$
4,0	$2,4 \cdot 10^{-3}$	$2,7 \cdot 10^{-3}$	$4,3 \cdot 10^{-3}$	$9,3 \cdot 10^{-3}$	$2,6 \cdot 10^{-2}$	$1,2 \cdot 10^{-3}$
5,0	$1,9 \cdot 10^{-3}$	$2,2 \cdot 10^{-3}$	$3,5 \cdot 10^{-3}$	$7,4 \cdot 10^{-3}$	$2,4 \cdot 10^{-2}$	$2,3 \cdot 10^{-3}$
6,0	$1,6 \cdot 10^{-3}$	$1,8 \cdot 10^{-3}$	$2,9 \cdot 10^{-3}$	$6,0 \cdot 10^{-3}$	$2,2 \cdot 10^{-2}$	$6,0 \cdot 10^{-3}$
7,0	$1,3 \cdot 10^{-3}$	$1,6 \cdot 10^{-3}$	$2,5 \cdot 10^{-3}$	$5,5 \cdot 10^{-3}$	$1,9 \cdot 10^{-2}$	$8,8 \cdot 10^{-3}$
8,0	$1,1 \cdot 10^{-3}$	$1,4 \cdot 10^{-3}$	$2,2 \cdot 10^{-3}$	$4,8 \cdot 10^{-3}$	$1,7 \cdot 10^{-2}$	$1,2 \cdot 10^{-2}$
9,0	$1,0 \cdot 10^{-3}$	$1,2 \cdot 10^{-3}$	$1,9 \cdot 10^{-3}$	$4,2 \cdot 10^{-3}$	$1,6 \cdot 10^{-2}$	$1,4 \cdot 10^{-2}$
10,0	$9,2 \cdot 10^{-4}$	$1,1 \cdot 10^{-3}$	$1,7 \cdot 10^{-3}$	$3,8 \cdot 10^{-3}$	$1,5 \cdot 10^{-2}$	$1,7 \cdot 10^{-2}$

Table II

Concentration as a function of the weather stability parameter at different distances X from the source.

X (km) \ λ	- ∞ 44 %	0,5 19 %	1,1 17 %	1,7 12 %	2,3 5 %	2,9 3 %
0,1	$6,6 \cdot 10^{-6}$	$5,9 \cdot 10^{-6}$	$3,9 \cdot 10^{-6}$	$1,8 \cdot 10^{-7}$	-	-
0,25	$1,3 \cdot 10^{-5}$	$1,4 \cdot 10^{-5}$	$1,7 \cdot 10^{-5}$	$1,1 \cdot 10^{-5}$	-	-
0,5	$7,9 \cdot 10^{-6}$	$9,2 \cdot 10^{-6}$	$1,3 \cdot 10^{-5}$	$1,7 \cdot 10^{-5}$	$1,1 \cdot 10^{-6}$	-
1	$4,0 \cdot 10^{-6}$	$4,8 \cdot 10^{-6}$	$7,0 \cdot 10^{-6}$	$1,2 \cdot 10^{-5}$	$7,2 \cdot 10^{-6}$	-
2	$1,8 \cdot 10^{-6}$	$2,2 \cdot 10^{-6}$	$3,3 \cdot 10^{-6}$	$6,6 \cdot 10^{-6}$	$1,2 \cdot 10^{-5}$	-
3	$1,2 \cdot 10^{-6}$	$1,4 \cdot 10^{-6}$	$2,2 \cdot 10^{-6}$	$4,4 \cdot 10^{-6}$	$1,1 \cdot 10^{-5}$	$7,5 \cdot 10^{-8}$
4	$8,8 \cdot 10^{-7}$	$1,1 \cdot 10^{-6}$	$1,6 \cdot 10^{-6}$	$3,4 \cdot 10^{-6}$	$9,7 \cdot 10^{-6}$	$4,8 \cdot 10^{-7}$
5	$6,6 \cdot 10^{-7}$	$7,9 \cdot 10^{-7}$	$1,3 \cdot 10^{-6}$	$2,7 \cdot 10^{-6}$	$8,8 \cdot 10^{-6}$	$1,2 \cdot 10^{-6}$
6	$5,7 \cdot 10^{-7}$	$6,6 \cdot 10^{-7}$	$1,1 \cdot 10^{-6}$	$2,3 \cdot 10^{-6}$	$7,9 \cdot 10^{-6}$	$2,2 \cdot 10^{-6}$
7	$5,3 \cdot 10^{-7}$	$5,9 \cdot 10^{-7}$	$8,8 \cdot 10^{-7}$	$2,0 \cdot 10^{-6}$	$7,0 \cdot 10^{-6}$	$3,2 \cdot 10^{-6}$
8	$4,3 \cdot 10^{-7}$	$5,3 \cdot 10^{-7}$	$7,9 \cdot 10^{-7}$	$1,8 \cdot 10^{-6}$	$6,2 \cdot 10^{-6}$	$4,4 \cdot 10^{-6}$
9	$3,8 \cdot 10^{-7}$	$4,4 \cdot 10^{-7}$	$7,0 \cdot 10^{-7}$	$1,6 \cdot 10^{-6}$	$5,7 \cdot 10^{-6}$	$5,5 \cdot 10^{-6}$
10	$3,4 \cdot 10^{-7}$	$4,0 \cdot 10^{-7}$	$6,2 \cdot 10^{-7}$	$1,4 \cdot 10^{-6}$	$5,5 \cdot 10^{-6}$	$6,3 \cdot 10^{-6}$

Table III

Integral concentration (kgs/m^3) at 50 and 95 % cumulative frequence.

Distance (km)	50 % cumulative frequence	95 % cumulative frequence
0,1	$1,5\cdot10^{-2}$	$1,8\cdot10^{-2}$
0,25	$3,6\cdot10^{-2}$	$4,4\cdot10^{-2}$
0,5	$2,15\cdot10^{-2}$	$4,1\cdot10^{-2}$
1,0	$1,1\cdot10^{-2}$	$2,8\cdot10^{-2}$
2,0	$5,0\cdot10^{-3}$	$1,8\cdot10^{-2}$
3,0	$3,3\cdot10^{-3}$	$1,3\cdot10^{-2}$
4,0	$2,4\cdot10^{-3}$	$9,3\cdot10^{-3}$
5,0	$1,9\cdot10^{-3}$	$7,4\cdot10^{-3}$
6,0	$1,6\cdot10^{-3}$	$6,1\cdot10^{-5}$
7,0	$1,4\cdot10^{-3}$	$8,8\cdot10^{-3}$
8,0	$1,3\cdot10^{-3}$	$8,0\cdot10^{-3}$
9,0	$1,0\cdot10^{-3}$	$6,0\cdot10^{-3}$
10,0	$9,3\cdot10^{-4}$	$5,4\cdot10^{-3}$

Table IV

Plume-width at 50 and 95 % cumulative frequence at different distances from the source.

Distance (km)	Plume-width (m) 50 % cumulative frequence	Plume-width (m) 95 % cumulative frequence
0,1	120	70
0,25	300	200
0,5	600	400
1,0	800	600
2,0	1.500	900
3,0	2.000	1.100
4,0	2.500	1.500
5,0	2.750	2.000
6,0	3.000	2.500
7,0	-	2.750
8,0	-	-
9,0	-	-
10,0	-	-

Table V

Concentration (kg/m^3) at 50 and 95 % cumulative frequence.

Distance (km)	50 % cumulative frequence	95 % cumulative frequence
0,1	$5,6 \cdot 10^{-6}$	$6,3 \cdot 10^{-6}$
0,25	$1,3 \cdot 10^{-5}$	$1,6 \cdot 10^{-5}$
0,5	$7,7 \cdot 10^{-6}$	$1,5 \cdot 10^{-5}$
1,0	$4,2 \cdot 10^{-6}$	$9,4 \cdot 10^{-6}$
2,0	$1,8 \cdot 10^{-6}$	$6,6 \cdot 10^{-6}$
3,0	$1,2 \cdot 10^{-6}$	$4,4 \cdot 10^{-6}$
4,0	$9,2 \cdot 10^{-7}$	$3,4 \cdot 10^{-6}$
5,0	$7,0 \cdot 10^{-7}$	$2,9 \cdot 10^{-6}$
6,0	$5,8 \cdot 10^{-7}$	$2,6 \cdot 10^{-6}$
7,0	$5,2 \cdot 10^{-7}$	$2,4 \cdot 10^{-6}$
8,0	$4,5 \cdot 10^{-7}$	$2,3 \cdot 10^{-6}$
9,0	$3,9 \cdot 10^{-7}$	$2,2 \cdot 10^{-6}$
10,0	$3,4 \cdot 10^{-7}$	$2,0 \cdot 10^{-6}$

Table VI

Amount of uranium deposited in the lungs of a man at different distances from the source.

Distance (km)	50 % cumulative frequence grams U deposited	95 % cumulative frequence grams U deposited
0,1	$1,3 \cdot 10^{-3}$	$1,6 \cdot 10^{-3}$
0,25	$3,1 \cdot 10^{-3}$	$3,8 \cdot 10^{-3}$
0,5	$1,8 \cdot 10^{-3}$	$3,6 \cdot 10^{-3}$
1,0	$9,5 \cdot 10^{-4}$	$2,4 \cdot 10^{-3}$
2,0	$4,3 \cdot 10^{-4}$	$1,6 \cdot 10^{-3}$
3,0	$2,9 \cdot 10^{-4}$	$1,1 \cdot 10^{-3}$
4,0	$2,1 \cdot 10^{-4}$	$8,1 \cdot 10^{-4}$
5,0	$1,6 \cdot 10^{-4}$	$6,4 \cdot 10^{-4}$
6,0	$1,4 \cdot 10^{-4}$	$5,3 \cdot 10^{-4}$
7,0	$1,2 \cdot 10^{-4}$	$7,6 \cdot 10^{-4}$
8,0	$1,1 \cdot 10^{-4}$	$6,9 \cdot 10^{-4}$
9,0	$8,6 \cdot 10^{-5}$	$5,2 \cdot 10^{-4}$
10,0	$8,1 \cdot 10^{-5}$	$4,7 \cdot 10^{-4}$

Table VII

Concentration of hydrofluoric acid in air at different distances from the source.

Distance (km)	mg/m^3 hydrofluoric acid 50 % cumulative frequence	mg/m^3 hydrofluoric acid 95 % cumulative frequence
0,1	1,8	2,1
0,25	4,3	5,3
0,5	2,5	4,9
1,0	1,4	3,1
2,0	0,59	2,2
3,0	0,40	1,5
4,0	0,30	1,1
5,0	0,23	0,96
6,0	0,19	0,86
7,0	0,17	0,79
8,0	0,15	0,76
9,0	0,13	0,73
10,0	0,11	0,66

Figure 1

UF$_6$ cylinder model 30B.

Figure 2

Temperature as a function of time.
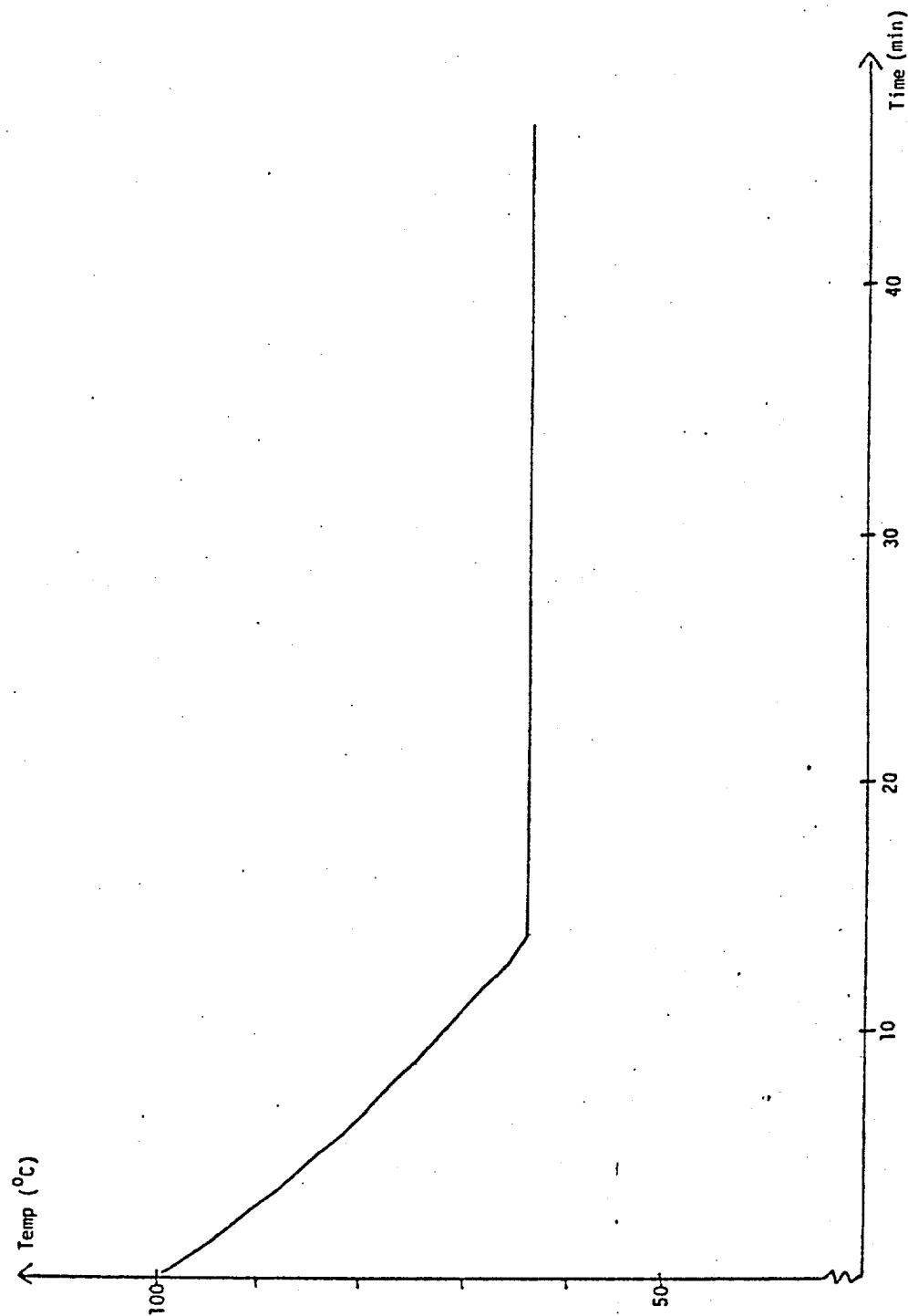
Starting point $100^{o}C$.
Holediameter 1".

Figure 3

Percent of cylinder content discharged as a function of time.
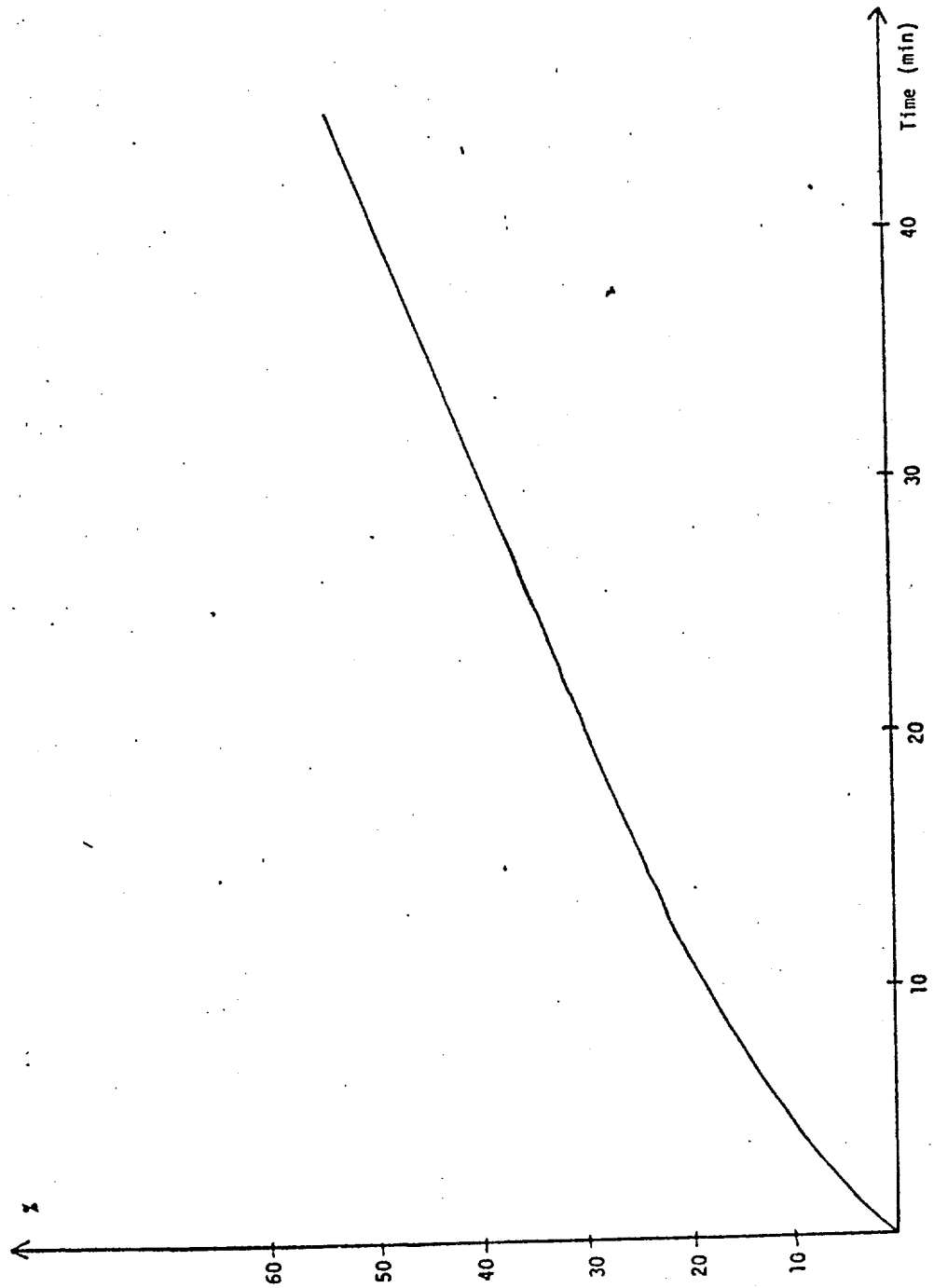Starting point 100°C.
Hole diameter 1".

Figure 4

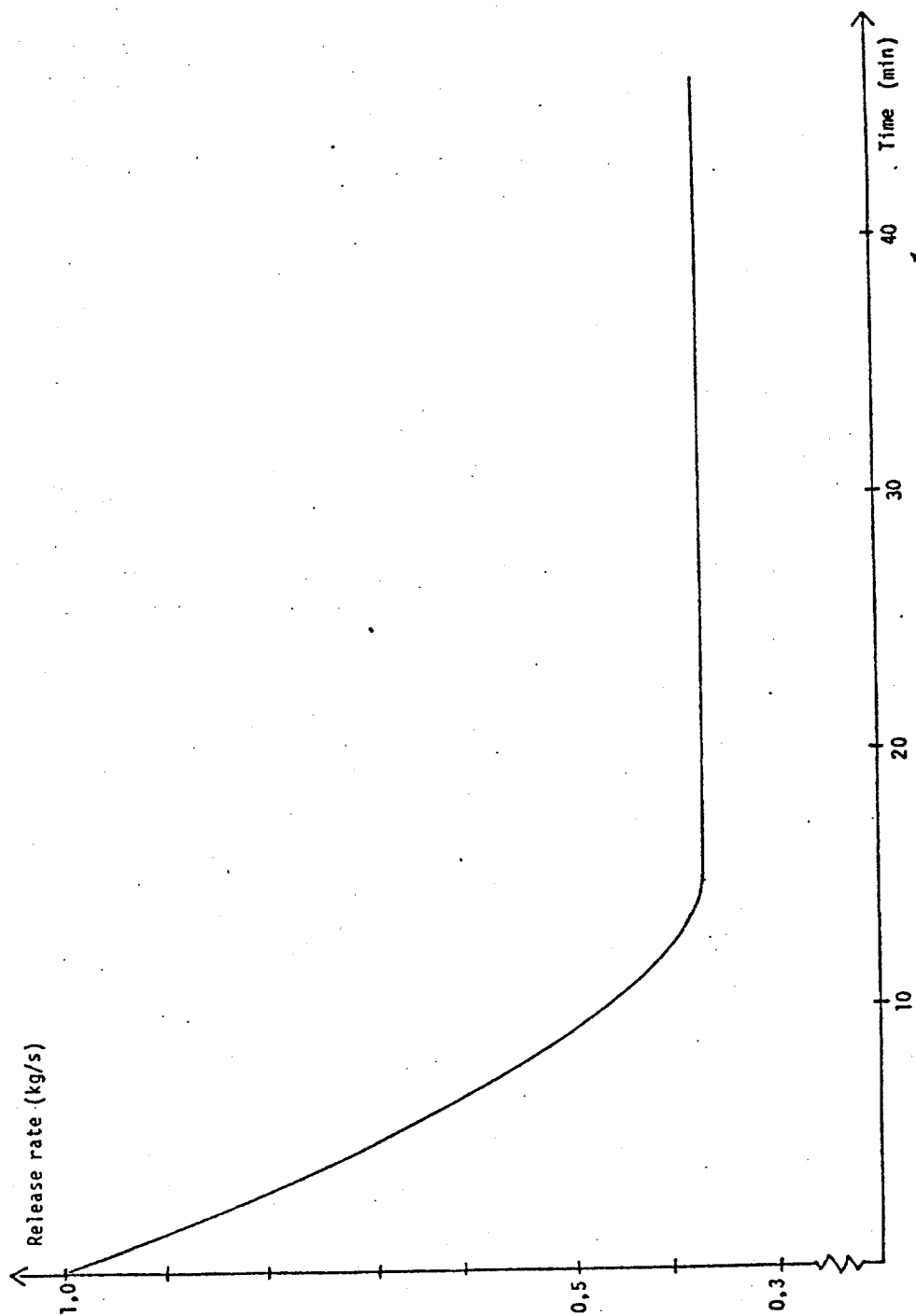Release rate as a function of time.

Starting point 100°C.
Holediameter 1".

Release rate (kg/s)

1,0

0,5

0,3

10   20   30   40   Time (min)

Figure 5

Integral concentration (kgs/m^3) = f (cumulative frequence)

1. 0,1 km from the source.
2. 0,25 "   "   "   " .
3. 0,5 "   "   "   " .
4. 1,0 "   "   "   " .
5. 2,0 "   "   "   " .
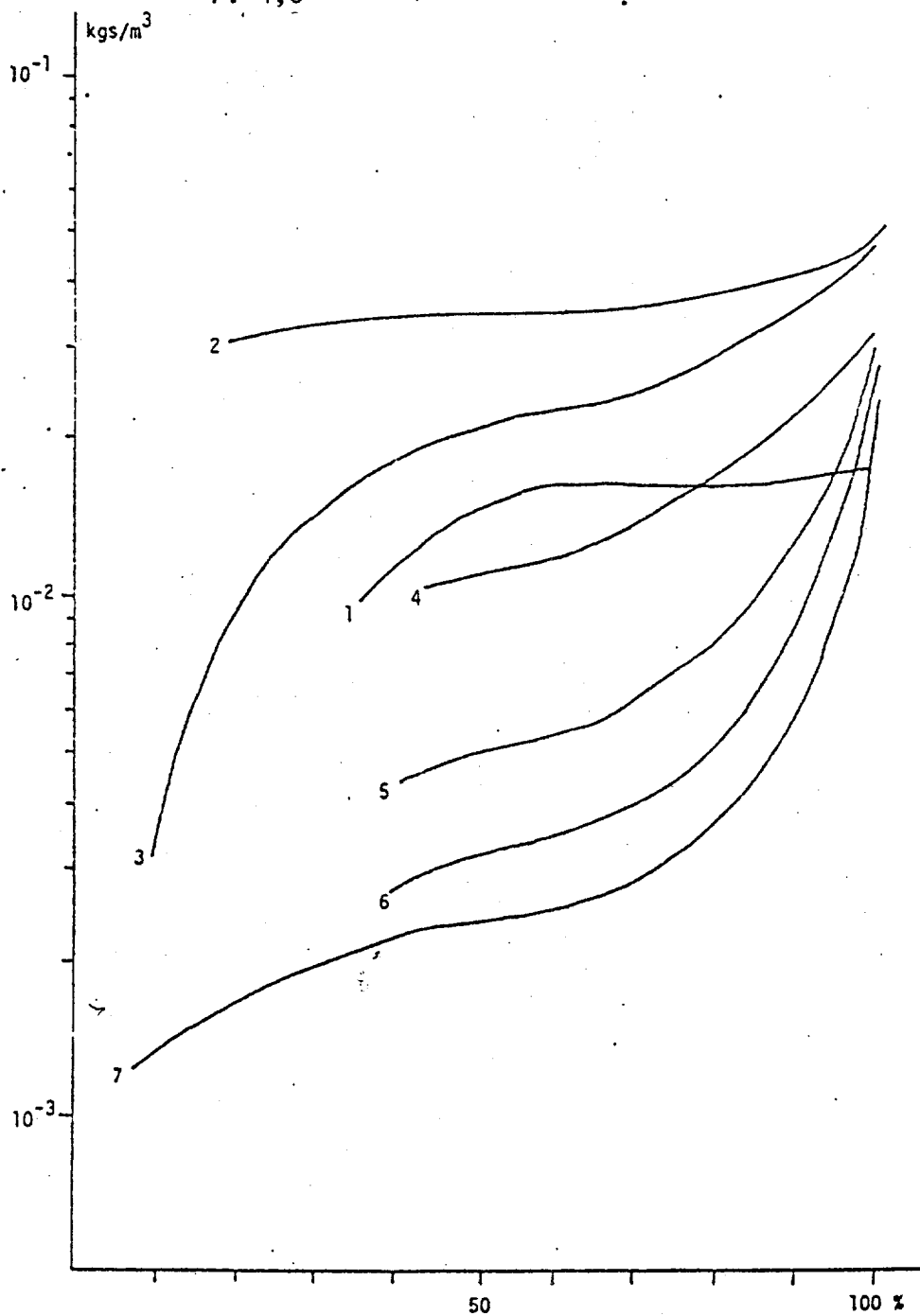6. 3,0 "   "   "   " .
7. 4,0 "   "   "   " .

Figure 6

Integral concentration (kgs/m^3) = f (cumulative frequence)

1. 5,0 km from the source.
2. 6,0 " " " " .
3. 7,0 " " " " .
4. 8,0 " " " " .
5. 9,0 " " " " .
6. 10,0 " " " " .